EP Performance Requirements for In-Situ Propellant Usage

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When envisioning a robust, continuous human space exploration program, two technologies often arise as mission enhancing: high specific impulse electric propulsion, and in situ propellant utilization. Often these two technologies are considered separately; the full benefit of using both is not often considered. This is due, in part, to the restricted range of propellants that present electric propulsion concepts such as ion and Hall thrusters can utilize without suffering dramatically decreased electrode lifetime due to electrode erosion or chemical interactions. However, some novel electrodeless concepts may remove the electrode erosion constraint and allow electric propulsion systems to utilize extraterrestrial propellants. The effectiveness of en route refueling for a high specific impulse system depends on two things: the thruster specific impulse and efficiency when using non-optimal but readily available propellants, and the savings in initial mass from reduced initial propellant loading. The thruster – mission performance trade space will be examined in a parametric manner, calling on existing thruster performance models and example mission trajectories to determine the propellant-power-specific impulse regime that yields an overall mission benefit.

A LEO – Moon (LLO) reuseable OTV which might utilize Lunar in situ propellants is considered. This entails an earth fueled transfer to LLO, followed by repeated operation using in-situ propellants to transport later payloads from LEO to the Moon. This mission allows the assumption of a constant ΔV, unlike more complex low thrust planetary missions in which performance can affect ΔV. Mission performance can then be expressed in terms of power system specific mass (α), exhaust velocity (u_e), and efficiency (η), by

$$e^{-\frac{\Delta V}{u_e}} = \frac{\mu + \frac{\alpha u_e^2}{2\eta\tau}}{1 + \frac{\alpha u_e^2}{2\eta\tau}}$$

Thruster performance is modeled using the equation

$$h = \frac{\text{Axial Kinetic Energy}}{\text{Total Input Energy}} = \frac{b u_e^2}{u_e^2 + d^2},$$

where $0 < b \leq 1$ is a parameter that indicates the efficiency of the acceleration mechanism in directing plasma axially, and d describes the energy input required to create each particle. The requirements on b and d for any system using in situ propellants to exceed the performance using optimized earth-launched propellants is analyzed.